Transport and Dispersion for a Potential Accidental Release of Radioactive Pollutants from the Nuclear Reactor at Cienfuegos, Cuba

Jerome L. Heffter
Barbara J. B. Stunder
National Oceanic & Atmospheric Administration
Air Resources Laboratory
Silver Spring, MD

August, 1992

Introduction

Radioactive pollutants released into the atmosphere will form a plume that can be transported and dispersed by air currents, thus reaching areas distant from the release location. It is of interest to determine the probability that a plume from a single release will impact (extend over and affect) a given location, the time of plume arrival, and the concentration at ground level when the plume is over the location. Since the magnitude of the release is unknown for this study, absolute concentrations cannot be determined, so concentrations are only considered in a relative sense.

It is therefore possible to construct maps of the probability of a plume impact, average time of plume arrival, and relative plume concentration from a single pollutant release, given the release location, meteorological data, a transport and dispersion model, and a statistical analysis program to determine the required results.

Meteorological Data

Meteorological data are routinely generated from the National Oceanic Atmospheric Administration (NOAA) National Meteorological Center forecast model runs (Peterson and Stackpole 1989). The run considered for this study uses the Medium Range Forecast (MRF) model (Sela, 1980), which provides meteorological data at 6-hour intervals on a polar stereographic grid with a spacing of 381 km. The NOAA Air Resources Laboratory (ARL) began archiving the MRF data in January, 1991 so only one complete year of data is presently available.

Transport and Dispersion Model

The Hybrid Single-Particle Lagrangian Integrated Trajectories (HY-SPLIT) model (Draxler, 1992) is routinely used at ARL for transport and dispersion modeling studies. The algorithms and equations used in the calculation of long-range pollutant transport and dispersion are a hybrid between Eulerian (fixed) and Lagrangian (moving) approaches. A single pollutant puff represents the initial source. Advection and diffusion calculations are made in the Lagrangian framework. As the dispersion of the initial puff spreads it into regions of different wind directions or speeds, it is divided into multiple puffs to provide a more accurate representation of the complex flow field. Air concentrations are calculated on a fixed three dimensional grid by integrating all puff masses over time.

Model Runs

The geographic domain in HY-SPLIT for a Cienfuegos release was a grid (95 km spacing) including all of the U.S. and Mexico, the western Atlantic, Gulf of Mexico, and the Caribbean Sea. For determining monthly plume statistics, a release was assumed every 6 hours for the month, with the transport following each release continuing for a duration of 5 days. This duration was chosen so all plumes would approach or cross the geographic domain boundaries.

Statistics

A specially designed interpretive statistical program calculated the probability of a plume impact, average time of plume arrival, and relative plume concentration at each grid point for a month. Monthly values were then combined to give seasonal values. (Since a limited amount of climatological data were available for the study, seasonal values were felt to be more representative for presentation than monthly values.)

The probability of a plume impact from an accidental release of radioactive pollutants at Cienfuegos, Cuba is shown in Fig. 1a and Fig. 1b for summer, 1991 (June, July, August) and winter, 1991-92 (December 1991, January 1992, February 1992) climatology, respectively. The maps presented here, which cover a smaller area than the HY-SPLIT geographic domain, are free of the larger domain boundary effects. As indicated at the upper right, Cienfuegos (22.1°N, 80.5°W) is shown on the maps as a "O". The coded percentages on the maps are explained at the lower left. The main feature of the probabilities in Fig. 1a shows relatively higher values to the west and northwest of Cienfuegos, reflecting the persistent summer east-to-west trade winds, and a drift toward the north into weak summer westerly flow. The trade winds are weaker and less persistent in the winter, as shown in Fig. 1b, and as a plume drifts toward the north, it encounters the strong winter westerly flow which then moves it towards the east. Fig. 2a and Fig. 2b show average time of plume arrival, in days, for summer and winter, respectively. The pattern of average arrival times in the Caribbean Sea and lower Gulf of Mexico areas is also related to the persistence of the trade winds. Northward drift into strong westerly flow in the winter gives earlier average arrival times over the southeast U.S. than in the summer. Figs. 3a and 3b show relative plume concentration for summer and winter when a plume is overriding. As indicated at the lower left, concentration symbols represent factor of 10 increments. Since no information is available about the release magnitude at Cienfuegos, these charts can be only used to compare relative concentrations between locations. Thus, relative concentrations at Miami, Florida and Houston, Texas are about the same in the summer (Fig. 3a, both near the top of the "-" increment), but are about 5 times smaller at Houston in the winter (Fig. 3b, Houston now being only midway through the "-" increment).

Comparison diagrams for plume impact probability, average time of arrival, and relative concentration are given for 4 locations of interest in Figs. 4a, 4b, and 4c, respectively. The chosen locations are at Miami, Florida, Tallahassee, Florida, Guantanamo, Cuba, and Houston, Texas. Comparison values are taken from seasonal summer and winter maps (Figs. 1 and 2) and also from spring and fall maps not shown here. Values are plotted as a "dot" which are connected by lines only for ease of visual comparison (i.e., no linear relationship should be inferred between seasons). Solid lines are for Miami, dashed for Tallahassee, dash-dot for Houston, and large dash-small dash for Guantanamo. The diagrams have been plotted so the higher the line, the worse the condition (i.e., higher probability of a plume impact (Fig. 4a), earliest average time of arrival - fewer number of days (Fig. 4b), and higher relative concentration (Fig. 4c)).

The main features of Fig. 4a show a comparatively high probability of a plume impact at Houston in the summer and a comparatively high probability at Tallahassee in the winter.

Note that there is a near zero override probability at Guantanamo in all seasons except winter. Average time of plume arrival, Fig. 4b, shows Miami with the earliest in all seasons, with the exception of Guantanamo in the winter (the only appreciable time with plume override), followed by Tallahassee, and then Houston with the latest average arrival times. The relative concentrations for a plume override, Fig. 4c, are the highest at Miami (Guantanamo is equivalent in the winter), with Tallahassee next, and the lowest at Houston.

References

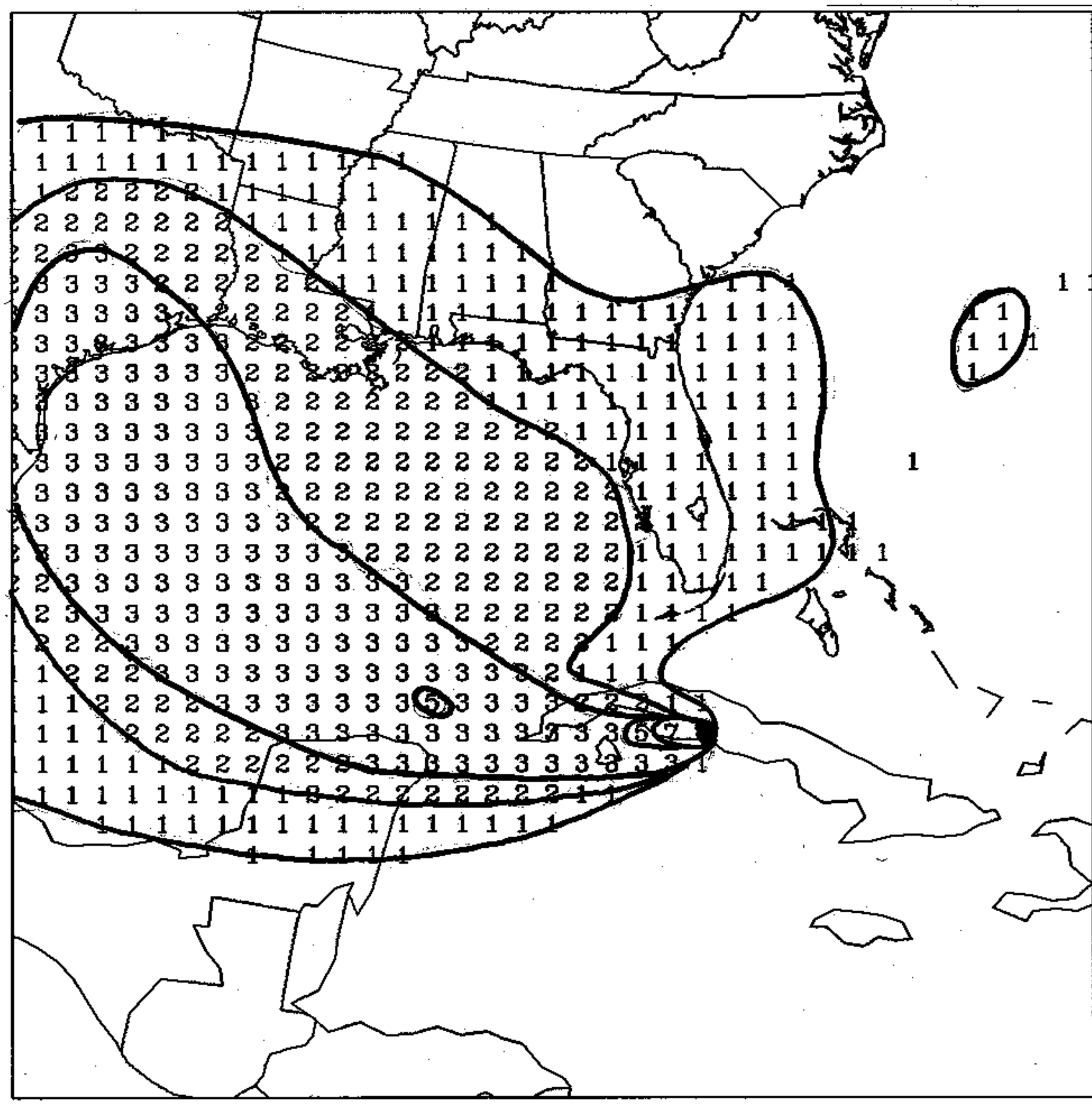
Draxler, R., 1992: Hybrid single-particle Lagrangian integrated trajectories (HY-SPLIT): Version 3.0 -- user's guide and model description, NOAA Technical Memorandum ERL ARL-195, June, National Technical Information Service, Springfield VA.

Petersen, R.A., and J.D. Stackpole, 1989: Overview of the NMC Production Suite, Weather and Forecasting, 4, (313-322).

Sela, J.G., 1980: Spectral modeling at the National Meteorological Center, Mon. Wea. Rev., 108, (1279-1292).

PROBABILITY OF A PLUME IMPACT (PERCENT)

CIENFUEGOS (●)
22.1°N, 80.5°W

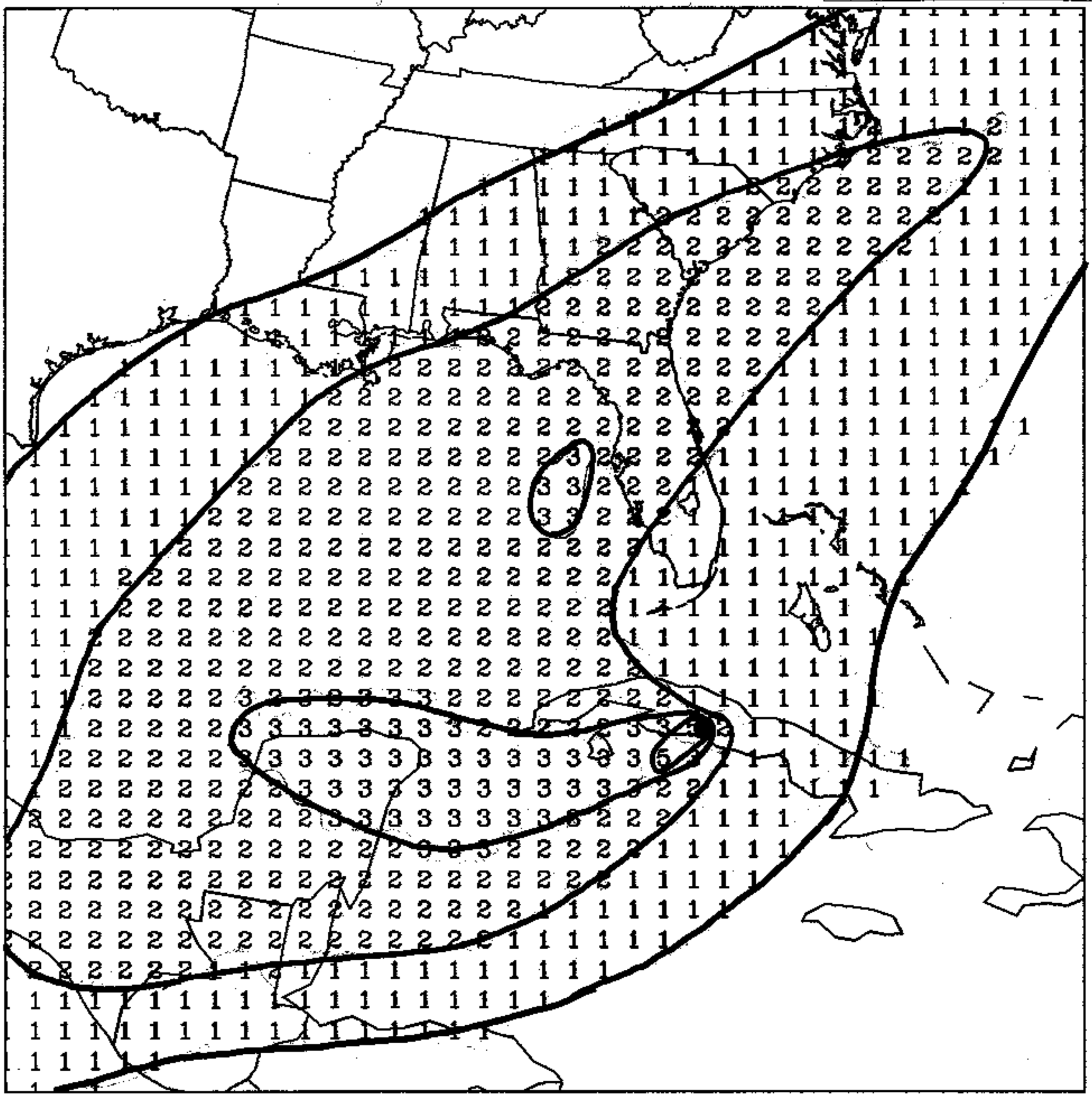


PERCENT= 10 – 20 – 30 – 50 – 70 – 90 – 100
CODE= 1 2 3 5 7 9

Figure 1a. Probability of a plume impact from an accidental release of radioactive pollutants at Cienfuegos, Cuba; based on summer climatology, 1991 (June, July, August).

PROBABILITY OF A PLUME IMPACT (PERCENT)

CIENFUEGOS (●)
22.1°N, 80.5°W



PERCENT= 10 – 20 – 30 – 50 – 70 – 90 – 100
CODE= 1 2 3 5 7 9

Figure 1b. Same as Fig. 1a, for winter 1991-92 (December 1991, January 1992, February 1992).

TIME OF PLUME ARRIVAL (DAYS)

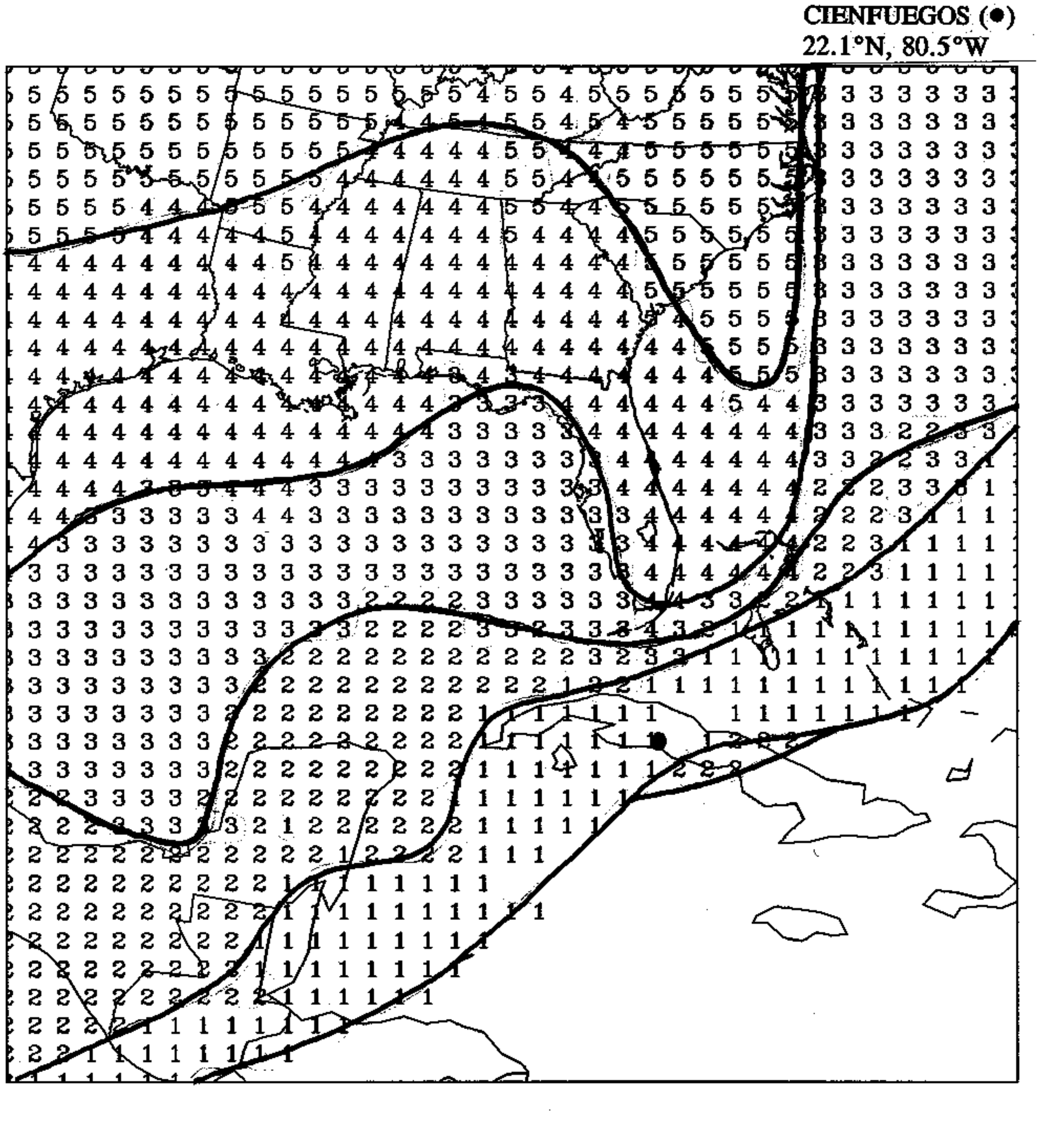


Figure 2a. Time of plume arrival, summer 1991.

TIME OF PLUME ARRIVAL (DAYS)

CIENFUEGOS (●)
22.1°N, 80.5°W

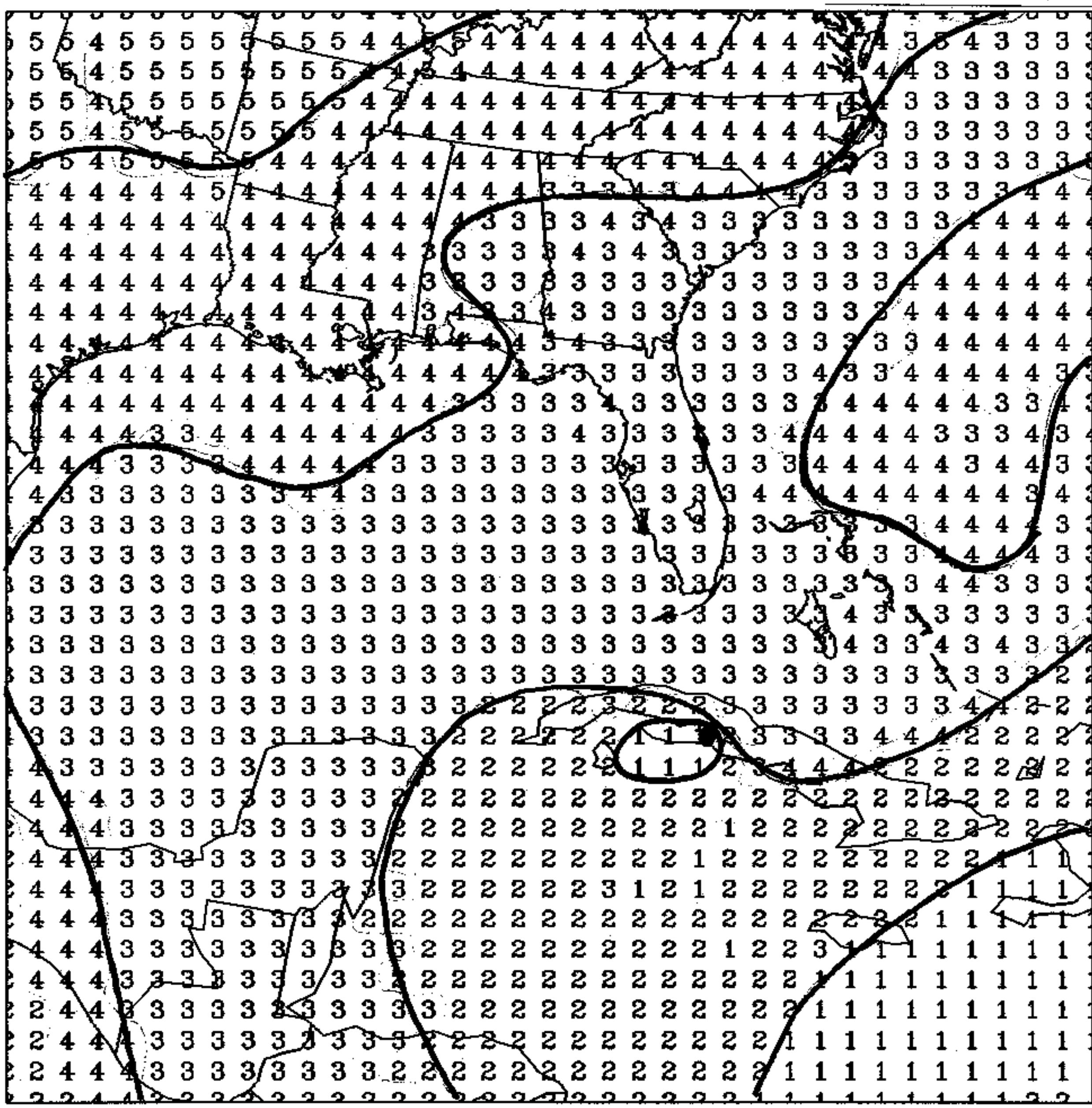


Figure 2b. Same as Fig. 2a, for winter 1991-92.

RELATIVE PLUME CONCENTRATION

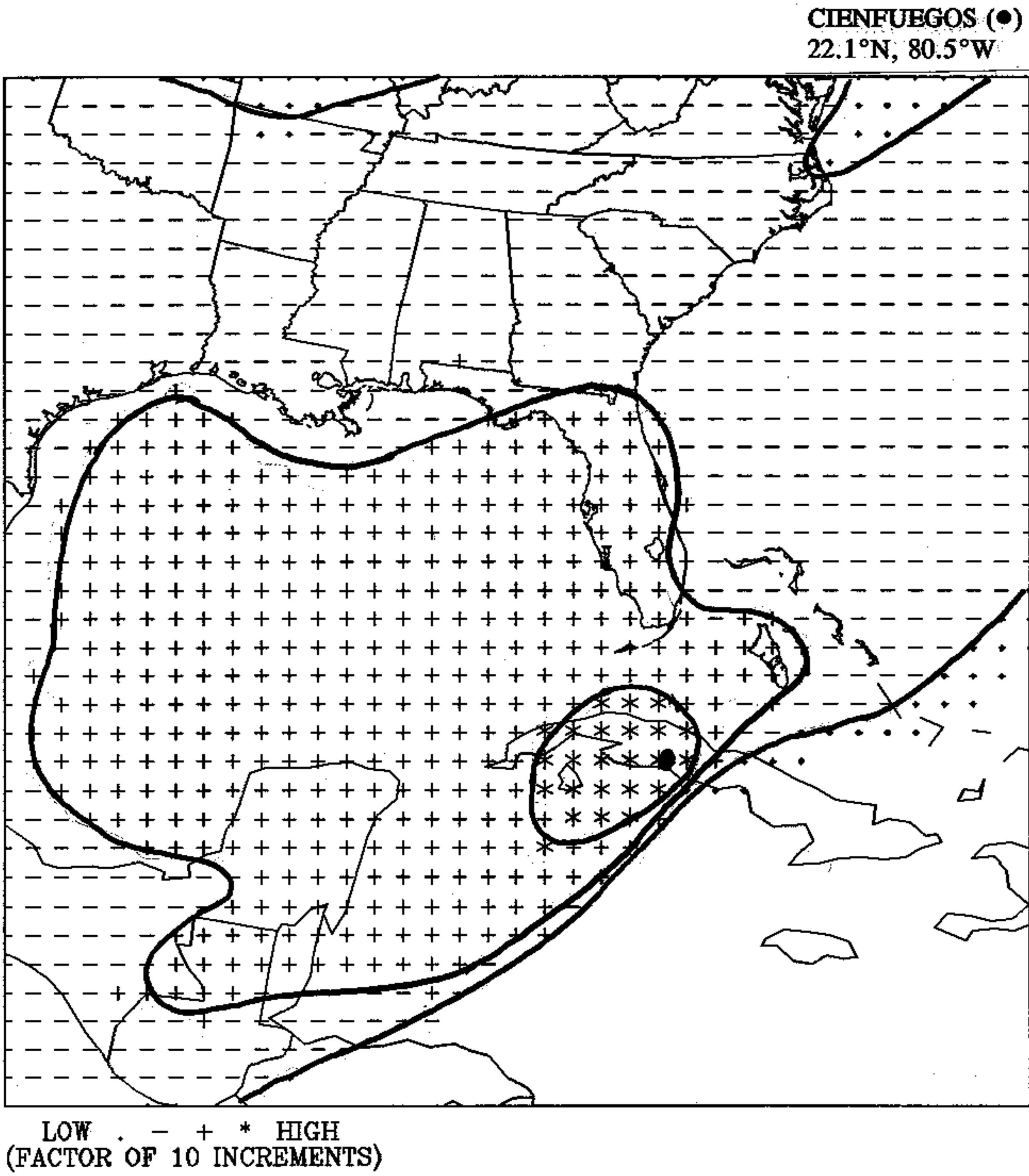


Figure 3a. Relative plume concentration, summer 1991.

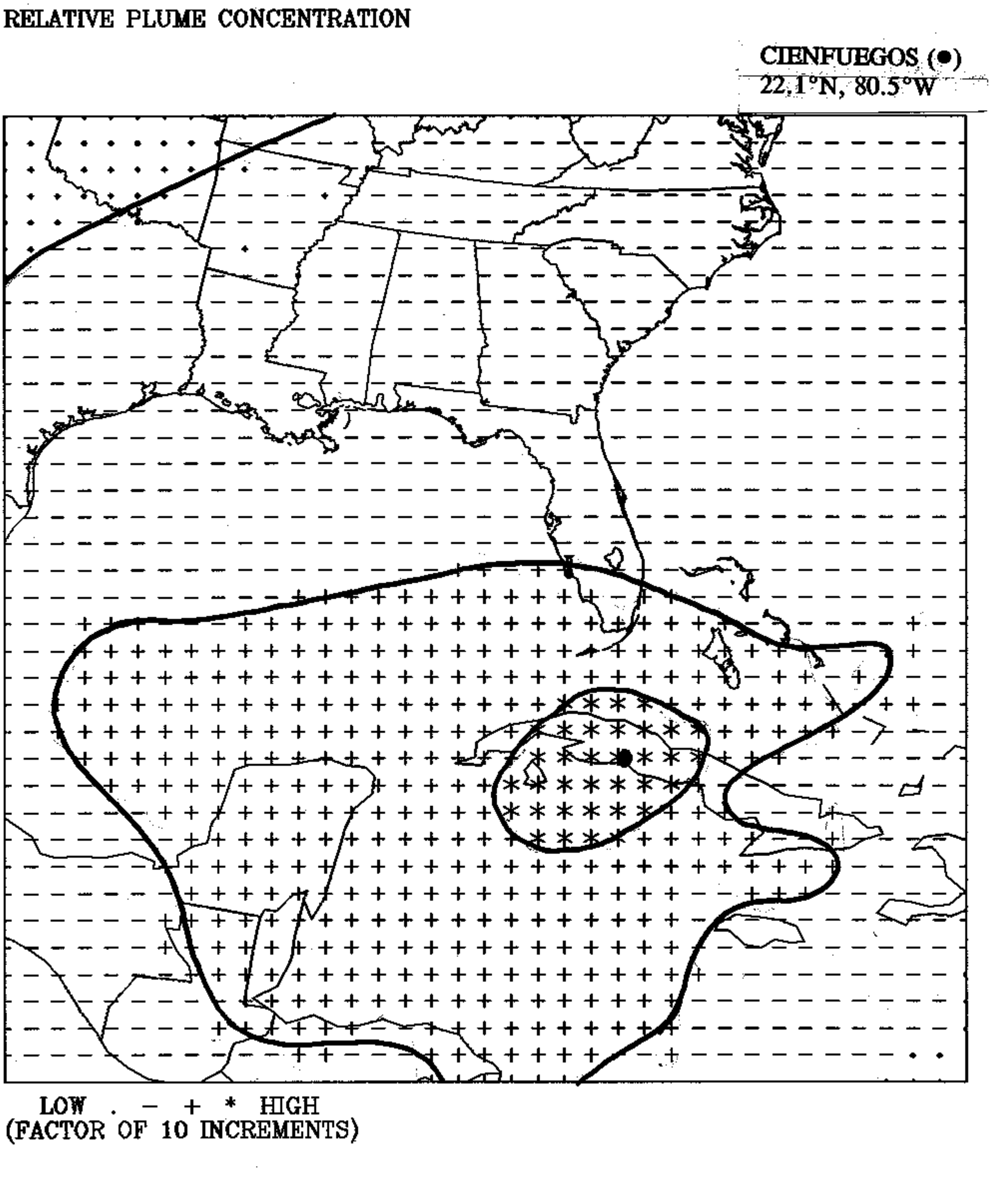


Figure 3b. Same as Fig. 3a, for winter 1991-92.

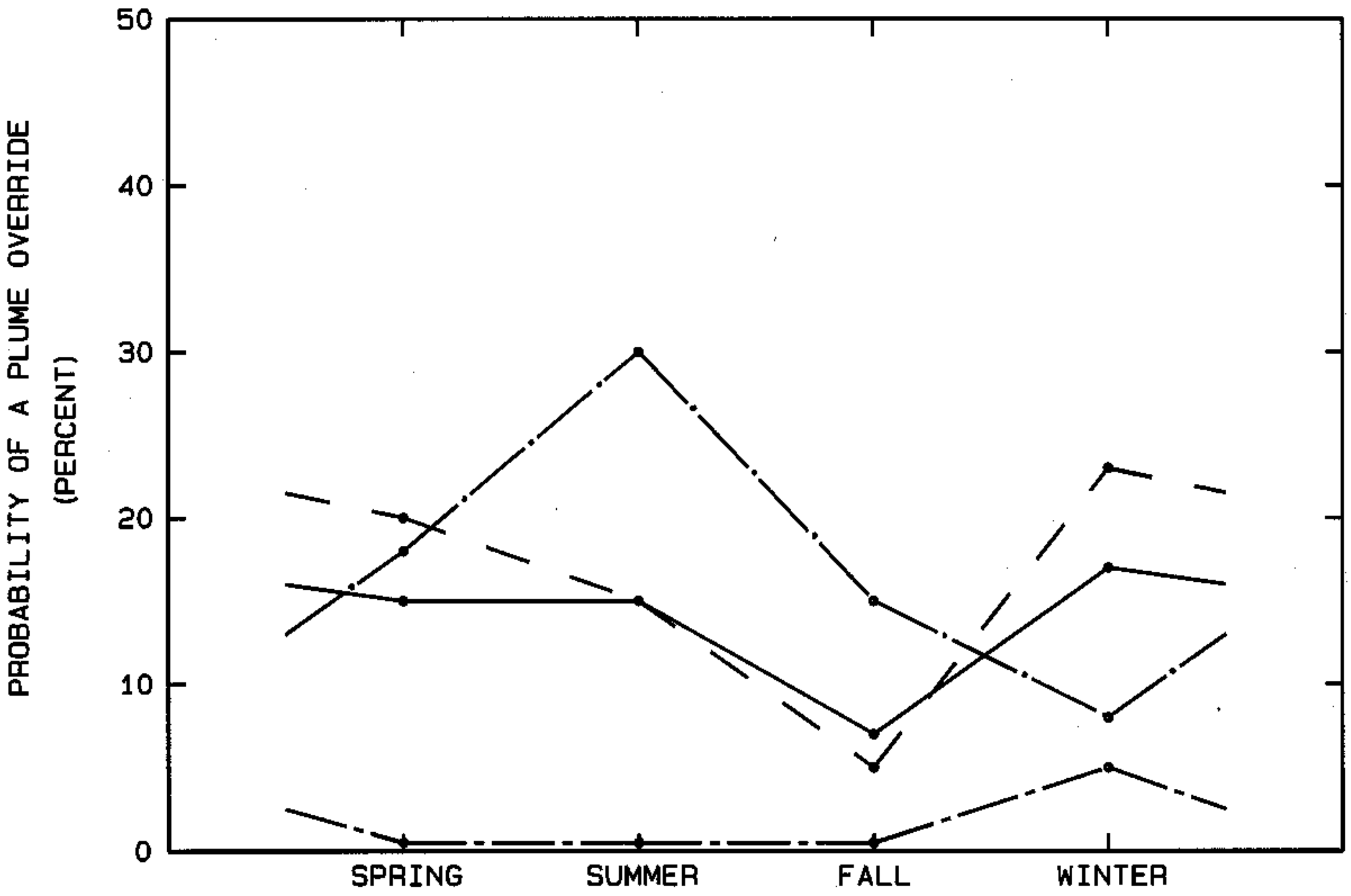


Figure 4a. Probability of a plume override, by season, for Miami, Florida (solid), Tallahassee, Florida (dashed), Houston, Texas (dashed-dot), and Guantanamo, Cuba (large dash-small dash).

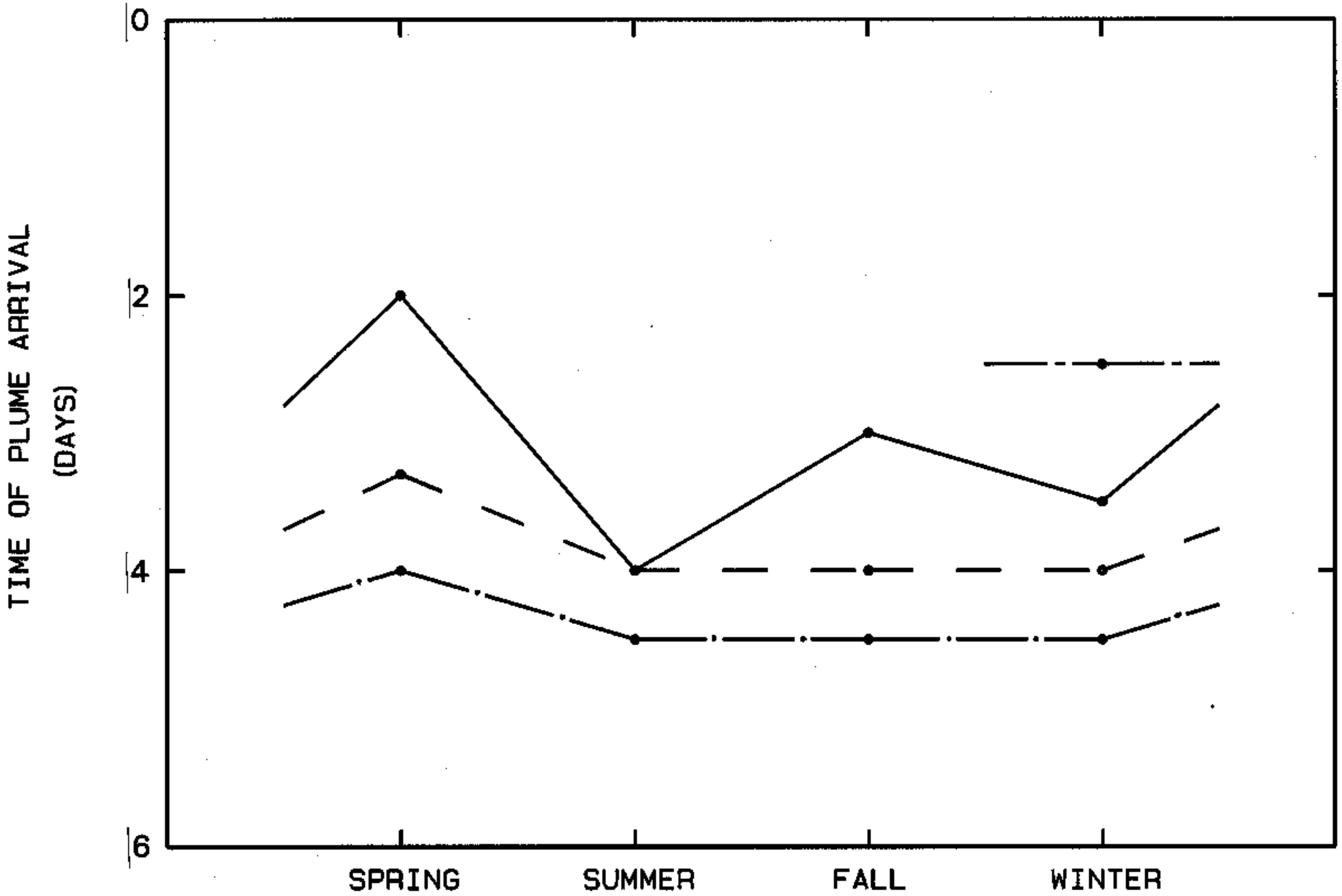


Figure 4b. Same as Fig. 4a, for time of plime arrival.

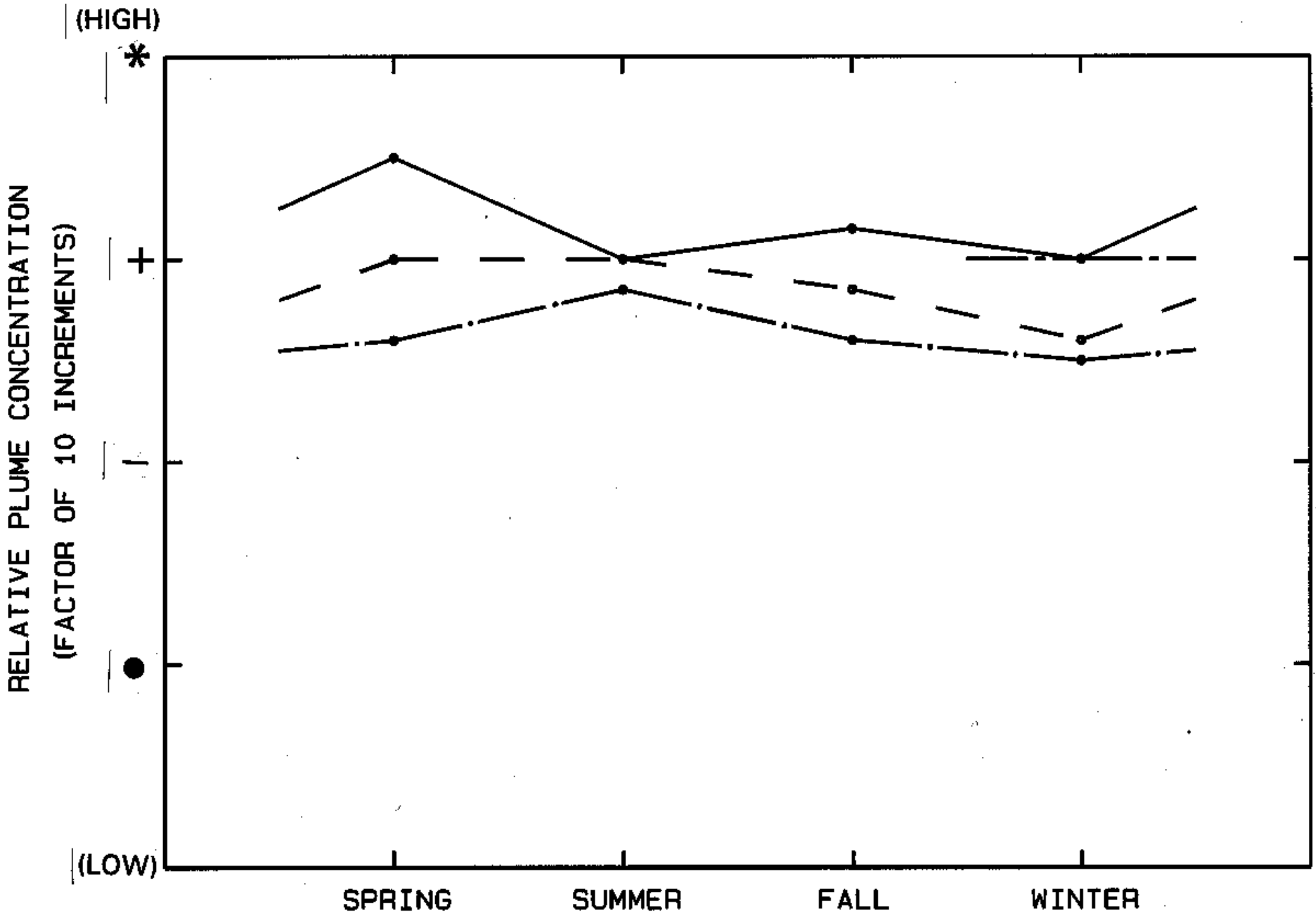


Figure 4c. Same as Fig. 4a, for relative plume concentration.